FUNCTIONAL RESIDUAL CAPACITY AS A NONINVASIVE INDICATOR OF OPTIMAL POSITIVE END-EXPIRATORY PRESSURE

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ABSTRACT. We hypothesized that functional residual capacity (FRC) could be used as a noninvasive indicator of “optimal” positive end-expiratory pressure (PEEP), the level of PEEP that results in venous admixture below 15% with an inspired oxygen fraction less than 0.5. We compared several variables for PEEP optimization—oxygen transport, total respiratory system compliance, FRC-based compliance, mixed venous oxygen saturation, end-tidal to arterial carbon dioxide tension difference, and arterial oxygen saturation—by producing four different PEEP levels, 0, 5, 10, and 15 cm H2O, in 24 mongrel dogs in which pulmonary injury was produced. The data were regressed versus PEEP by using analysis of variance for regression. Venous admixture ($F_{1,23} = 149.3; P < 0.0001$), end-tidal to arterial carbon dioxide tension difference ($F_{1,23} = 64.9; P < 0.0001$), and oxygen transport ($F_{1,23} = 95.1; P < 0.0001$) decreased linearly with PEEP. FRC ($F_{1,23} = 248.1; P < 0.0001$) and arterial oxygen saturation ($F_{1,23} = 66.9; P < 0.0001$) increased linearly with PEEP. Total respiratory system compliance ($F_{1,23} = 66.6; P < 0.0001$) and mixed venous oxygen saturation ($F_{1,23} = 12.2; P < 0.002$) had a quadratic relationship with respect to PEEP with a peak at 5 cm H2O. FRC-based compliance did not have a significant relationship to PEEP. The maximum values of total respiratory system compliance, FRC-based compliance, mixed venous oxygen saturation, and oxygen transport did not occur at PEEP levels that corresponded to a venous admixture below 15% (“optimal” PEEP). In this canine oleic acid lung injury model, maximizing these variables would be a poor technique for PEEP titration. FRC and arterial oxygen saturation had a strong relationship to PEEP and venous admixture, and these two would be good noninvasive variables for use in PEEP titration.

KEY WORDS. Ventilation: mechanical; positive end-expiratory pressure. Lungs: functional residual capacity.
be measured easily in vital organs, PEEP is often optimized by using venous admixture (Qva/Qt) [3,6–9]. A wide variety of different techniques have been proposed for optimizing PEEP therapy. One of these, “optimal” PEEP, has been defined as the PEEP level that results in a Qva/Qt less than 15% with an FiO2 less than 0.5 in the face of maintained cardiac output [3,6–9]. In general, Qva/Qt has been the standard variable to assess the effects of PEEP in acute lung injury. Measurement of Qva/Qt requires measurement of arterial and mixed venous blood gases. Suter et al [10,11] have suggested that PEEP be adjusted to the level that results in the maximum oxygen transport (CaO2 • Qt). (This PEEP level has been referred to as “best” PEEP.) Calculation of oxygen transport requires measurement of arterial blood gases and cardiac output. Some authors have proposed a less invasive technique that would minimize the difference between end-tidal carbon dioxide tension (PetCO2) and arterial carbon dioxide tension (PaCO2) [10,12,13] (ΔCO2). An arterial blood gas measurement and sampling of expired gas are required for this technique.

Two different noninvasive PEEP optimization techniques based on lung compliance have been used. It has been noted in some patients that the PEEP level that provides maximum oxygen transport corresponds to the maximum lung compliance (C1) [3,10,11,14]. C1 or even an estimate of it based on total respiratory system compliance (Csr) is difficult to measure in conscious, unparalyzed patients because it is influenced by skeletal movement. In patients with stiff lungs, C1 decreases with PEEP [7,8,15–18]. A measurement of compliance based on functional residual capacity (FRC) (Cfrc), which takes into account both slow and fast compartments of the lung, has been used to overcome this problem [17]. Cfrc is calculated by using the PEEP-induced change in FRC: Cfrc = (FRC1 – FRC2)/(PEEP1 – PEEP2).

The availability of sophisticated optical devices for measuring oxygen saturation, such as pulse oximeters for noninvasively measuring arterial oxygen saturation (SaO2) and fiberoptic pulmonary arterial catheters for measuring mixed venous oxygen saturation (SvO2), have sparked an interest in their use as guides for PEEP optimization. Nelson et al [19] have shown little difference in outcome or resource utilization between patients who had early, moderate arterial hypoxemia and had PEEP adjusted to achieve nearly complete arterial saturation and those who had PEEP adjusted to reduce Qva/Qt below 20%. Their study did not deal with adult respiratory distress syndrome (ARDS) but with individuals with mild respiratory insufficiency; therefore, it is not possible to generalize this to all patients with respiratory failure. Baele et al [20] have reported that continuous monitoring of SvO2 provided a “warning” system for deterioration in cardiopulmonary function.

Data from previous studies have indicated that PEEP levels that maintain FRC at near-predicted normal levels coincided with optimal PEEP [2,10,15,17]. The purpose of our study was to compare FRC with other indicators used for PEEP optimization in an animal model of ARDS.

**METHODS**

A system was used similar to one we described previously [21] for closed-loop control of PEEP (Fig 1). The system consisted of a Siemens 900I servo ventilator (Siemens-Elema, Solna, Sweden) interfaced to an IBM PC/AT via an IEEE-488 bus interface, a Siemens 930 CO2 analyzer, and a sulfur hexafluoride (SF6) washout FRC measurement system [22]. The SF6 washout FRC measurement system consisted of a Siemens prototype infrared analyzer [23], a tank of 100% SF6, and a flow controller to adjust the amount of SF6 delivered to the subject. The IBM PC/AT controlled PEEP, made FRC calculations, and collected all the other online ventilator information.

After receiving approval from our Animal Research Review Board, we investigated 24 mongrel dogs weighing between 20 and 25 kg. Anesthesia was induced with thiopental (20 mg/kg) and maintained with a pentobarbital drip as necessary to maintain mean arterial blood pressure at 100 mm Hg. The animals were paralyzed with pancuronium (2 mg/h). Their tracheas were intubated and the animals were ventilated with an